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TITLE: FAR INFRARED FARADAY-ROTATION MEASUREMENT ON A REVERSED-FIELD-PINCH PLASMA

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FAR INFRA-RED FARADAY ROTATION MEASUREMENT ON A REVERSED-FIELD-PINCH PLASMA

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Abstract

The integral $\int n_e B_\theta \cdot d\ell$ is measured on the Los Alamos reversed field pinch plasma (ZT-40) by the rotation of the linear polarization of the 185 μm emission of a CO_2-pumped CH_2F_2 laser. The essence of the method is to monitor phase distortions of the regular beat frequency produced when two counter-rotating circular polarizations, frequency shifted with respect to each other and sent along a common off-center chord through the plasma, are detected behind a linear polarization analyzer. Rotations are measurable to the order of 0.01 cycles. The same frequency shifted beams have been used with linear polarizations in a heterodyne interferometer configuration to give $\int n_e \, d\ell$ with high sensitivity. Work is in progress to make both measurements simultaneously.

The poloidal magnetic field in ZT-40 (a toroidal reversed-field-pinch controlled fusion experiment) is being measured by Faraday rotation of the 184.6 μm emission of a CO_2 pumped CH_2F_2 laser. The essence of this method, which is independent of spurious intensity modulations, is to monitor the phase distortions of a regular beat frequency. This beating is produced when two opposite-circularly polarized components, frequency shifted with respect to each other and both passed through a magnetized plasma, are transmitted through a linear polarization analyzer. The same concept has been independently described by Dodel and Kunz.[1]

An Apollo model 118 FIR laser is being used as the radiation source. This laser has been modified with a photoacoustic cell feedback loop to control the CO_2 pump laser tuning. The gas handling system for the FIR laser has been changed to a static fill system with a cryogenic recovery unit for conservation of the CH_2F_2 gas. The laser output at the 184.6 μm wavelength with 24 W pump power is in excess of 125 mW.

Beam conditioning in the doubly-shielded laser screen room produces co-linear orthogonal polarizations frequency shifted with respect to each other any chosen amount up to 1 MHz. This is achieved by beam splitting with a wire grid polarizer, reflecting one beam off a rotating grating, and recombining the beams with the same polarizer.

The maximum frequency offset is achieved when the 17-cm radius aluminum disk, which has the grating machined on its rim and is positioned so that the incident and reflected wave-guided beams both obey the Bragg condition and strike the wheel horizontally well below the horizontal diameter, is spun at 100 rps. This set-up is pictured in Fig. 2. A properly oriented quarter-wave plate converts the orthogonal linear polarizations to orthogonal circular polarizations. A rotatable half wave plate prior to the beam splitter is used to equalize the intensities in both components after beam recombination. The beam conditioning is shown schematically in Fig. 3.

The beams are next passed through ~ 17 meters of 2.5 cm i.d. dielectric waveguide including six 90° corners to the plasma device.

The radiation is detected after passing through the plasma device by a liquid-He cooled epitaxial GaAs layer detector. This is shown schematically in Fig. 4. In the absence of plasma the counter-rotating circular polarizations of differing frequency produce a uniformly rotating linear polarization that is converted to a sinusoidal intensity modulation by a linear polarization analyzer in front of the detector. In the presence of a magnetized plasma, the phase velocity of one circular polarization is speeded up and the other is slowed down giving rise to a distortion of the periodicity. The output signal, therefore, is analogous to the signal from a heterodyne interferometer, with the same advantages of insensitivity to intensity variations, phase resolution independent of instantaneous phase angle, and time resolution comparable to the heterodyne frequency.

The measured angular rotation in radians is equal to $2.63 \times 10^{-17} \lambda^2 \int nB \cdot d\ell$ with λ the laser wavelength (cm), n the plasma electron density (cm^{-3}), B the magnetic field (gauss), and $d\ell$ the differential path element along the laser beam (cm). Computerized data acquisition with a 10-bit transient waveform digitizer enables us to read phase distortions to about 0.01 cycle accuracy, by comparing the waveform during the plasma discharge with the waveform obtained exactly one revolution later of the grating wheel. One cycle of intensity modulation equals π radians. The data analysis determines the waveform frequency as well as phase shift and the wheel inertia between consecutive rotations renders the analysis for plasma rotation angle independent of long term wheel frequency drifts.

Figure 5 shows typical data over the first two milliseconds of a 200 kA toroidal current discharge for Faraday rotation along a minor cross-section chord offset by 12.5 cm "impact parameter" from the geometrical center. The wavy "base-line" is a comparable analysis for a "no plasma" discharge--i.e., $n_e \approx 0$ and the driving capacitor bank discharging into the metallic liner vacuum chamber. It indicates that the first negative spike is due to a very large signal amplitude disturbance (electromagnetic pick-up) that is also readily seen in the raw data intensity modulation, whereas the remaining wiggles are well below the 0.01 cycle claimed accuracy. The decreasing plasma signal trend is known to be due to a density decay, whereas the fluctuations are a combination of density and field turbulence.

By removing the quarter wave plate a heterodyne interferometer working with frequency shifted orthogonal linear polarizations was set up in the configuration shown schematically in Fig. 6. In this case a phase shift of 1 cycle results for $\int n_e \, d\ell \approx 1.2\times10^{15}$ cm^{-2}. The larger phase shift enables the signal to be followed for the entire 6 ms duration of the discharge. Detailed agreement with a multi-chord CO_2 laser heterodyne interferometer[2] for the first two milliseconds is excellent. After that time the latter gets into vibration problems, illustrating the well-known fact that longer wavelengths help not only due to larger electron refractivity but also by lowered vibration sensitivity, since a given mechanical motion is a correspondingly smaller fraction of a full wavelength modulation.

Work is currently proceeding on a) simultaneous polarimetry and interferometry and b) expansion to a multi-chord system in order to convert line integrals to localized values by inversion techniques.

Acknowledgments

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References

1. G. Dodel and W. Kunz, Infrared Physics 18, 773 (1978).

2. A. R. Jacobson and L. I. Jolin, SPIE Vol. 288, 1981, Paper B211.